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Art. X.—*The Older Volcanic and Tertiary Marine Beds at Curlewis, near Geelong.*

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Introduction.

Curlewis Railway Station lies about 9 miles east of Geelong, and the beach is about $1\frac{1}{2}$ miles north of the station. The geological interest of the area is in the Tertiary rocks which are exposed along the sea-cliffs and, at low tide, on the shore-platforms. Older Volcanic rocks, and Tertiary marine clays and limestones outcrop in close proximity at many places on the beach, and their stratigraphical relationship has been the subject of some controversy. Earth movements have produced some interesting folding and faulting of the Tertiary rocks.

Previous Work.

Three papers dealing with Curlewis have been published. Daintree(1), who was in charge of the boring for coal in the Bellarine Peninsula about 1861-2, stated the Tertiary succession to be—

Lower Pliocene ferruginous sandy clays.

Lower Pliocene (Older Volcanic) basalt and tuff.

Miocene limestone and calcareous sandstone.

Eocene (or Lower Miocene) sands and clays.

His evidence for classing the Older Volcanic as Lower Pliocene was obtained in two shafts, 4A and 5A near Mannerim, where the Older Basalt rested on a bed of quartz pebble drift, which he regarded as Lower Pliocene.

Hall and Pritchard(2) examined the area in 1894. They classed both the limestone and the marine clays as Eocene, and demonstrated that the limestone overlies the Older Volcanic tuff. Their view of the succession reads—

Lower Pliocene sands, gravels, clays.

Eocene limestone and marine clays.

Eocene or pre-Eocene (Older Volcanic) tuff and basalt.

Describing the faulting and folding of the hard limestone band, which at low tide can be seen projecting as a reef about 2 feet above the level of the beach, they said: "The amount of disturbance in the Eocene strata here is apparently unparalleled in Southern Australia, and is evidently merely local. . . . The high dip, contortion, and changed character of the small area of polyzoal rock exposed point to subsequent volcanic disturbance, although no trace of igneous rock overlying the fossiliferous strata was found. Possibly no great discharge of solid material took place, but heated gases caused the slight metamorphism of the limestone. The Clifton mineral springs, plentifully charged with CO_2, possibly represent the dying or solfatara stage of this outburst."

Three years later, the same authors withdrew their suggestion that the limestone had been partially metamorphosed, and put forward (3, p. 212), the explanation that the changed character of the rock was due to induration. Taking a broad view of the structural relations of the limestones to the underlying beds at Keilor, Maude, Airey's Inlet, Point Addis, Grange Burn, Curlewis, and Batesford, they noted that the bedrock is comparatively impervious, while "the typical polyzoal limestone is very open and porous, and it consequently offers a free channel to the passage of underground waters, which would accumulate in them in such localities and thus bring about the solution and re-deposition of the calcareous matter and so destroy in places all evidence of organic contents." Apparently they retained the hypothesis of subsequent volcanic activity as the cause of the disturbance of the Tertiary rocks.

In 1914, F. Chapman (4, p. 37) described the limestone and associated marine clays as of Miocene (Janjukian) age. His view of the succession may be expressed—

Lower Pliocene (Kalimnan) sands.

Miocene (Janjukian) volcanic ash, tuff, and agglomerate.

Miocene (Janjukian) { yellow and brown clays. / polyzoal limestone. / greenish sandy clay. / blue clay.

Miocene (?) volcanic ash.

He thus makes two divisions of the Older Volcanic rocks, stating (p. 38): "The view here maintained, that the main volcanic series occurs above the yellow limestone and under the Kalimnan grits, is the same as that brought forward by Daintree in 1861. . . . The present occurrence of Older Basalt as high as the top of the Janjukian is unique in the experience of the writer, for it generally occurs interbedded with or underlying the sedimentaries of that epoch."

Summary of Work Done.

I suggest the following succession:—

Lower Pliocene sands, ferruginous grits and gravels.

Lower Pliocene remanié phosphatic nodule bed.

Miocene (Janjukian) { grey clay. / hard polyzoal limestone. / blue, grey, and yellow clays.

Miocene (Older Volcanic) tuff and basalt.

It will be seen that this is in accordance with Hall and Pritchard's views as to the stratigraphical relations of the volcanic rocks to the clays and limestone, but accepts Chapman's view as to the age of the latter. I collected fossils wherever possible, and Mr. R. A. Keble, palaeontologist to the National Museum, wrote of those he had examined, that "Nothing had appeared to refute Mr. Chapman's claim that they are Janjukian." I am therefore adhering to this term for the Tertiary marine beds, one and all.

The accompanying map shows the faulting and folding of the area. I have been unable to establish the cause of the disturbance, but in what follows I suggest the most likely agency.

Some outcrops of "very hard siliceous limestone," noted on Quarter Sheet 23 S.E. to the east of Drysdale Jetty, concerning which the survey could not state the age owing to the absence of fossils, are shown to include pebbles of the Lower Pliocene beds, and are regarded as post-Pliocene to Recent in age.

Older Volcanic Series.

Extensive beds of lapillaceous tuff are exposed. Hall and Pritchard (2, p. 2) estimated the total thickness at 300 feet, with which figure I agree. The only basalt visible is the small basaltic neck ("dyke") near Ad. 12. This is no doubt a filled-in vent, as the size of the ejected material is greatest near it. Here there are large blocks of vesicular basalt, up to 3 feet diameter, embedded in the finer material. There are also, as noted by Hall and Pritchard (2, p. 3) rare blocks of altered sandstone, which appear to be derived from the Jurassic beds underlying the Cainozoics of the Bellarine Peninsula. I examined some of these included blocks microscopically, and they proved to be felspathic sandstone similar to the Jurassic type.

The solid rock at the basaltic neck is black, fine-grained, with small phenocrysts of olivine, and has a characteristic hackly fracture. Microscopically it is an olivine andesine basalt, consisting of olivine partly altered to serpentine, pale violet augite, laths of andesine felspar, and iron oxides as microphenocrysts and rods.

The rock thus belongs to the Older Basalt type. The ejected basalt in the tuffs was too altered and decomposed to cut rock sections from, but microscopically resembles that of the neck.

In what follows I show that the Tertiary marine beds, both clays and limestone, overlie the Older Volcanic rocks, both tuffs and basalt. Hall and Pritchard proved this relationship only for the limestone and the tuffs.

Although at Curlewis there do not appear to be any fossiliferous Cainozoic beds underlying the Older Volcanic, there are almost certainly some gravels between the Older Volcanic and the bedrock of Jurassic. Daintree (*loc. cit.*) probably encountered some of these and regarded them as Older Pliocene. I suggest that they are Miocene, similar to those near Maude. Now at Maude the Older Basalt, which is lithologically similar to the Curlewis type, occurs interbedded between limestones. The gravels (quartz pebble drift) occur at the base of the lower limestone. Both the upper and lower beds of these limestones are Lower Miocene in age, according to Mr. Chapman (personal communication) so there the Older Basalt must be Lower Miocene. By correlation it would be safe to call the Curlewis Older Basalt Miocene in age.

Miocene (Janjukian) Marine Series.

The variable colour of the clays has no stratigraphical significance. It may be due to the degree of oxidation of the pyrite and marcasite which occur as nodules in the black clay. The clay surrounding some of these nodules is impregnated with gypsum.

The limestone band is clearly interbedded with the clays, for along the western and eastern reefs and at Clifton Springs the clays can be seen both underlying and overlying the limestone.

Owing to its more resistant nature, the limestone band has preserved for us the effects of the earth movements from which the Tertiary series and the Older Volcanics have suffered. The western reef is contorted as a result of intense local folding, while the three reefs show numbers of small faults. Hall and Pritchard briefly discussed this faulting and folding, and attributed it to a recurrence of volcanic activity without any actual extrusion. Most of the faults appear to be dip faults. Some of the smaller may be horizontal (heave) faults due to the lateral displacement of the beds when they fractured in the arc of a severe fold, as in the western reef. Assuming the majority to be dip faults, the greatest throw (vertical displacement) for a definite fault is 30 feet, and the average throw about 5 feet. Some of the larger intervals between limestone outcrops, if regarded as faults, would give much higher figures for the throw. However, the whole system of faults indicates an extensive and shallow disturbance, with a trend parallel to the coast, rather than a single movement of great magnitude.

The hard "siliceous limestone" without fossils, which outcrops on the beach just east of Drysdale jetty, is really an incrustation of dolomitic travertine on the exposed edges of the Miocene clays. It contains pebbles of ironstone, quartz, &c., from the Lower Pliocene beds, and beach sand of Recent aspect, forming a hard sandy limestone grading into a fine conglomerate. On Quarter Sheet 23 S.E. it is marked as Tertiary, but from the nature of the included material it must be post-Pliocene to Recent in age. Mr. J. G. Doyle analyzed some of the finer-grained rock for me, with the following results:—

	Per Cent.
SiO_2	2.86
R_2O_3	5.26
CaO	33.68
MgO	15.28
CO_2	42.27
Total ..	99.35

The rock is thus cemented by a dolomitic matrix. The probable explanation is that the water-bearing Miocene clays are exposed on the edges of the cliffs, and the water being heavily charged with magnesian and calcareous salts, deposits these as carbonates around the arenaceous material on the cliff face and the beach.

Stratigraphical Relations.

Apart from Curlewis, there are only two places on the Bellarine Peninsula where the relationship of the Miocene marine beds to the Older Volcanic can be observed. Both are near Bellarine village, about 4 miles west of Portarlington. One is shown on Quarter Sheet 23 S.E. as a patch of Tertiary limestone exposed in a road cutting about 1 mile east of Bellarine village. Here the limestone overlies the Older Basalt. The other locality is not shown on Quarter Sheet, but is a road-metal quarry in the Older Basalt on " Spray Farm," north of Bellarine village. Here, again, the Tertiary limestone can be seen resting on the basalt.

In the area mapped, the polyzoal limestone always overlies the tuffs. This is clearly seen on the beach and the low cliff at Ad. 12, near the basaltic neck. The lower portion of this limestone contains worn pebbles of the Older Basalt.

The indurated pink limestone (" marble ") described by Hall and Pritchard (*loc. cit.*) was carefully examined at its irregular contacts with the underlying tuffs and basalt. A number of rock sections of these basalt-limestone contacts, and of the indurated limestone, were made. There is no trace in any of these of metamorphic minerals. The fossils have been very little altered, and identifiable foraminifera are common. Calcite fills the interstices and cavities in the fossils, but it merely replaces the calcareous mud of the original rock. Some ferro-calcite and possibly siderite is present close to the contacts, and there are also crystals of haematite and impregnating limonite in small amount. The reddish colour of the indurated rock is due to these iron oxides. They have probably formed from mineral matter leached out of the underlying volcanic rocks. Mr. Doyle analyzed some of the pink indurated limestone, with the following result:—

	Per Cent.
CaO	52.61
MgO	1.79
CO_2	42.18
Fe and Al oxides	1.79
Acid insoluble	1.86
Total ..	100.23

The evidence of relative age is less clear when the marine clays and the tuffs are considered. At several places on the cliffs near Ad. 12 the grey clay, which for the most part lies on top of the tuffs, can be seen as irregular veins filling former fissures and cavities in the surface of the tuffs. On the beach just west of the basaltic neck, and at Clifton Springs, near the baths jetty, small pockets or "potholes" of marine clay, especially rich in fossil cowries, occur in the surface of the tuffs.

At the basaltic neck the limestone and clay seems at first sight to have been fused into the lava; the marine rocks are very hard and tough close to the contacts. Microscopic examination revealed no metamorphic minerals, and the change is purely metasomatic, as was the case for the "marble."

By the test of superposition, applied to all the outcrops where both occur, the Older Volcanic series of basalt and tuff is therefore antecedent to the Miocene (Janjukian) marine limestone and clays.

In certain places there is no Janjukian bed between the Older Volcanic and the Lower Pliocene sands and gravels. This is the case in the cliffs near the baths jetty at Clifton Springs. Chapman (4, p. 38) mentions this, and assuming that the tuffs here represent an upper division of the Older Volcanic, states that these tuffs must overlie the Janjukian marine beds. The absence of the Janjukian at this point, however, is due to their removal by post-Miocene pre-Lower Pliocene denudation. About 20 yards seaward from the foot of this very cliff, one can find at low tide several "potholes" of richly fossiliferous Janjukian clay in the upper surface of the tuffs which here form the beach floor.

The accumulations of remanié phosphatic nodules at certain places between Ad. 12 and Ad. 14 indicate(5) that considerable denudation of the Janjukian marine beds took place prior to the deposition of the Lower Pliocene sands.

Mr. Chapman's contention that there are two divisions of the Older Volcanic is based on his interpretation of the section on the cliff at Ad. 12, on the east side of the gully near the Bellarine beacon. He states, "The section of the cliff showed a bed of tenacious blue clay resting on an ash bed, and above this a polyzoal limestone about 5 feet thick. This is surmounted by about 13 feet of basalt, and on this is a layer of hill wash." I have examined this section very carefully, and find that the blue clay and polyzoal limestone are not interbedded with the volcanic rocks. If they were, they would show all along the cliff face, whereas the outcrop is confined to the one small area. On digging in at the sides of the blue clay and the polyzoal limestone, I found that they rest on the tuffs, which are continuous beneath them. The Janjukian beds thus overlap and are unconformable with the tilted beds of tuff, and represent the lower marginal beds of the marine series, deposited on a rather steep bank of tuff. The true structure is depicted in the accompanying sketch (Fig. 1).

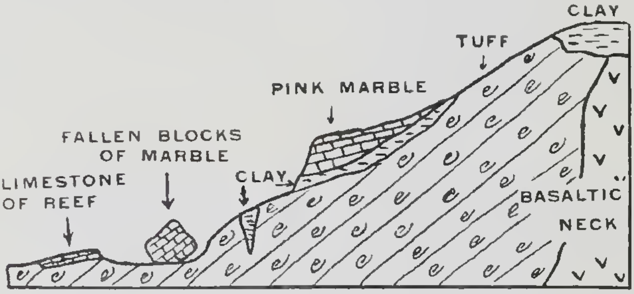

FIG. 1.—Sketch Section at Ad. 12. (Bellarine Beacon.)

The Older Volcanic series of tuffs and basalt is therefore a single formation, not two divisions as suggested by Chapman.

Cause of the Faulting and Folding.

The dips of the tuff beds are radially disposed about three separate centres, viz., Ad. 12, Ad. 14, and the beacons east of Ad. 14. The limestone outcrops are marginal to these semicircular outcrops of tuff, and though not conformable with them, have suffered the same disturbance, so that the directions of dip of the limestone are also radially disposed. Thus the earth movements must have been post-Janjukian.

Owing to their unbedded and incoherent character, the Lower Pliocene sands do not exhibit any marked folding or faulting such as occurs in the beds under them. It seems possible, however, that they shared in the disturbance. Where the Lower Pliocene ironstone outcrops on the beach near the fisherman's hut just west of Clifton Springs Hotel, the beds are tilted at about 10° to the north. The surface on which the Lower Pliocene deposits rest is slightly undulating, resulting in these beds being brought down to sea level at intervals along the coast, and in their absence from the higher parts owing to the levelling effect of atmospheric denudation.

It seems probable that the earth movements were subsequent to the deposition of these arenaceous beds, which following the Survey I have called Lower Pliocene. Chapman (4, p. 39) suggests that they are Kalimnan. No fossils have been found in them.

The cause of the folding is even more obscure than the age. Several suggestions have been made.

1. Daintree (quoted in Chapman, *loc. cit.*) stated, "The argillaceous limestone . . . has been upheaved by the intrusive basalt, and where the limestone was sufficiently pure it has been converted into a coarse kind of marble." The basalt referred to is that of the basaltic neck, but I have shown that this is part of the Older Volcanic series, which is antecedent to the Tertiary marine beds, and could not therefore have caused the disturbance. The conversion of the limestone into marble was due, as shown previously, to induration.

2. Hall and Pritchard (*loc. cit.*) ascribed the effects to "subsequent volcanic disturbance without much discharge of solid material." The Clifton Mineral Springs, plentifully charged with CO_2, possibly represent the dying or solfatara stage of this outburst." The gas bubbling up through the water in the springs at Clifton Springs contains about 95 per cent. of CO_2, but only minute traces of SO_2 can be detected in either the gas or the water. One might expect more SO_2 if the origin of the gas were volcanic; possibly its origin is organic. In the latter connexion it is well to remember that both the underlying Janjukian and Jurassic strata contain carbonaceous rocks.

3. As far as can be ascertained, the Curlewis beach is the only disturbed area of Tertiary rocks in the Bellarine Peninsula; around Lake Connewarre and at Wallington they are fairly horizontal. Likewise throughout the Geelong district they are fairly horizontal, except at Waurn Ponds. Here there is a definite monocline with the Janjukian beds downwarped about 50 feet to the north. The monocline can be seen in the limestone quarries on the Colac-road at Waurn Ponds. The axis of this monocline runs, roughly, east and west, and if produced would coincide with the trend of the reefs at Curlewis. This suggests that the same tectonic movement may have been responsible for both.

This and the other tectonic features of the Geelong district, viz., the Anakie fault and the Lovely Banks fault, are probably associated with the Newer Volcanic period of Upper Pliocene to Pleistocene age. It is a difficulty with this hypothesis to account for the locally severe disturbance at Curlewis. Possibly the subsidence of Geelong Outer Harbour and the formation of the north-south fault scarp (?) of the Leopold-Kensington hill contributed to the local intensity of the effects.

Summary of Conclusions.

1. There is only one Older Volcanic series.

2. It underlies the Miocene (Janjukian) marine series, but is probably Miocene in age.

3. The folding and faulting are probably due to Newer Volcanic tectonics.

Acknowledgments.

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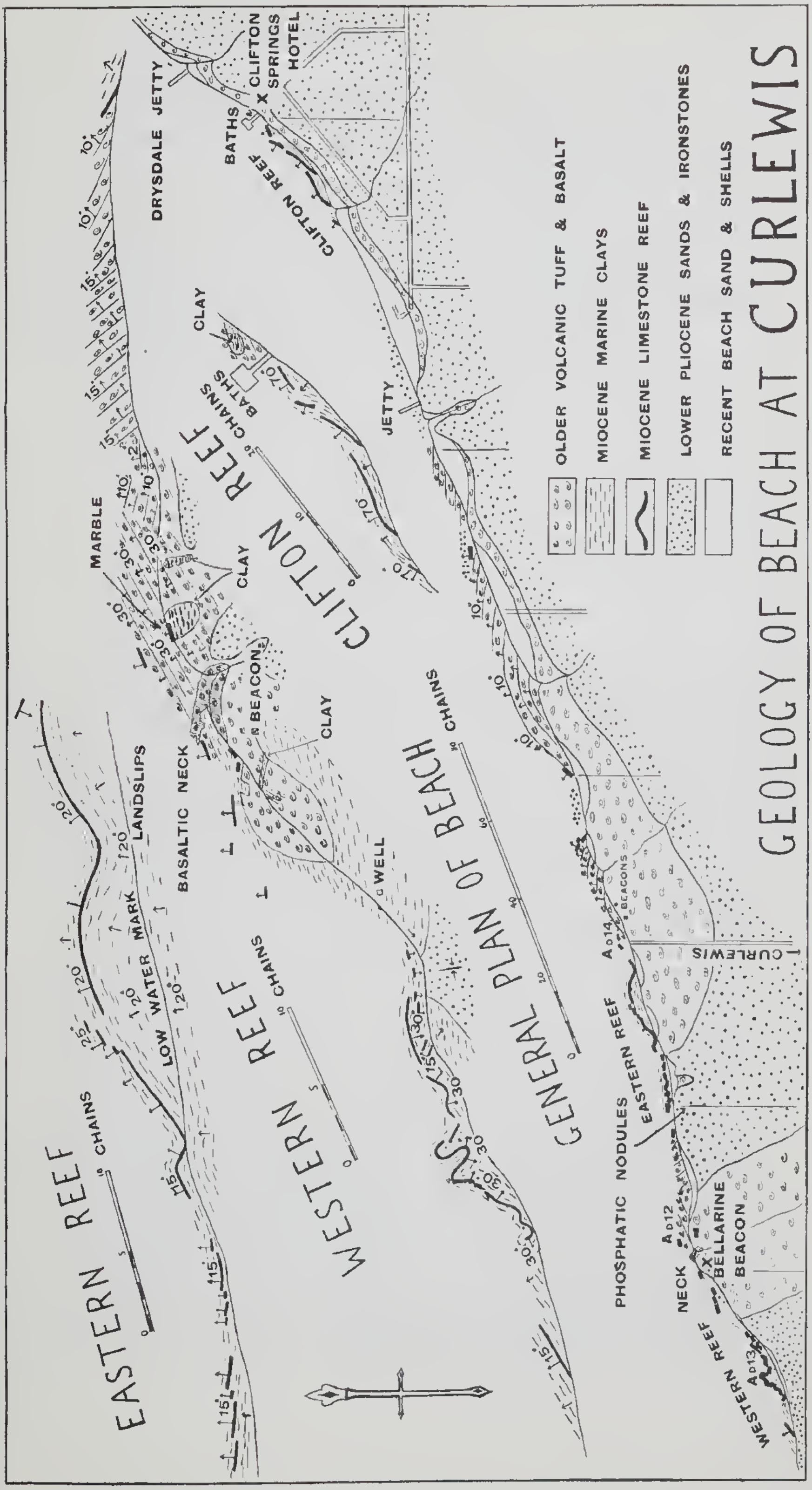
GEOLOGY OF BEACH AT CURLEWIS
OLDER VOLCANIC TUFF & BASALT
MIOCENE MARINE CLAYS
MIOCENE LIMESTONE REEF
LOWER PLIOCENE SANDS & IRONSTONES
RECENT BEACH SAND & SHELLS
GENERAL PLAN OF BEACH
EASTERN REEF
WESTERN REEF
CLIFTON REEF
CHAINS
DRYSDALE JETTY
CLIFTON SPRINGS HOTEL
BATHS
MARBLE
CLAY
BEACON
BASALTIC NECK
LANDSLIPS
LOW WATER MARK
WELL
JETTY
BEACONS
CURLEWIS
PHOSPHATIC NODULES
NECK
BELLARINE BEACON